180th Meeting of the Machine Protection Panel

The meeting took place on **August 30th 2019** in 774/1-079.
Participants: A. Apollonio, G. Arduini, J. A. Ferreira Somoza, B. Lindstrom, A. Lombardi, E. Mahner, B. Mikulec, M. O'Neil, D. Nisbet, C. Rossi, S. Ramberger, F. Roncarolo, B. Salvachua, R. Scrivens, B. Schofield, R. Steerenberg, F. Tecker, J. Uythoven, C. Wiesner, D. Wollmann

The slides of all presentations can be found on the website of the Machine Protection Panel and on Indico.

1.1 Aim and context of meeting (David Nisbet)

- David Nisbet introduced the aim and context of the meeting. The special MPP meeting should **review the topic of continuous caesiation at LINAC4**. Therefore, it should discuss the risks involved, the technical implementations and planned interlocks, as well as the experience in other accelerator laboratories and at the LINAC4 test stand.
- The MPP should summarize its findings and make a recommendation to the LINAC4 project team taking into consideration the comments of the reviewers and MPP members. The **findings and recommendations will be distributed** together with these minutes and will also be published on the website of the Machine Protection Panel and on Indico.
  - The reviewers especially invited to the MPP meetings are: Suitbert Ramberger (RF), Brad Schofield (ICS), Jose Antonio Ferreira Somoza (VSC), Rende Steerenberg (OP), Jan Uythoven (MPP meeting chairman), David Nisbet (LINAC4 MPP Linkman)

1.2 Introduction to continuos Caesiation (Alessandra Lombardi)

- Alessandra Lombardi introduced the questions of **one-shot caesiation in comparison to continuous caesiation**.
- The LINAC4 ion source uses caesium (Cs) to increase the surface production of H^- ions, and improve the ratio between extracted electrons and H^- ions (e^-/H^- ratio). The undesired electrons are deposited at a dedicated electron dump located at the puller electrode.
- For the currently used **one-shot caesiation**, the sector valve located upstream of the RFQ has to be closed before Cs can be introduced into the source by heating the Cs reservoir and transfer line. This protection functionality is guaranteed by a hardware interlock.
  - The **sector valve** is located in the LEBT upstream the second solenoid at ~1.4 m from the ion source. The RFQ entrance is located at ~2 m.
  - The caesium reservoir contains either 2 g or 5 g of Cs, depending on the type of ampulla used.
  - The one-shot caesiation requires a ~2 hour stop at least once a month.

- The **continuous-caesiation mode** has been proposed at the LIU meeting in Montreux in February 2019 as part of the ion source upgrades that could already be implemented for the LBE run.
- The **main benefit expected from continuous caesiation** is a higher long-term (i.e. not shot-to-shot) stability of the ion source, in particular concerning the H^- current and the electron-to-H^- ratio.
    - Without continuous caesiation, the ion source performance degrades by ~1mA/day. In operation, this can be compensated by increasing the RF power. However, this increases the undesired electron extraction and requires additional operational tuning to find back the optimum working point of the ion source.
- Additional benefits from the continuous caesiation mode are:
    - The periodic stop of beam operation (~2 hours at least once a month) with the sector valve closed is no longer required.
    - The load on the electron dump is reduced.
- Jan Uythoven asked if there has been experience with continuous caesiation at LINAC4. Alessandra Lombardi replied that up to now continuous caesiation was only used at the test stand, but not in the tunnel at LINAC4, except for a period of a few days with closed vacuum valve.
- Daniel Wollman asked if a change in the **dynamic vacuum** can be observed during caesiation. Edgar Mahner replied that there is no visible effect.
- Jan Uythoven asked if the Cs could have a detrimental **effect to elements located downstream of the RFQ**. Alessandra Lombardi replied that this possibility is excluded due to the length of the RFQ of ~3 m and its small aperture. There was a general agreement that the RFQ is the only critical element in the case of continuous caesiation.

1.3 Description of technical implementation by other labs (Edgar Mahner)

- Edgar Mahner compared various **Cs-driven ion sources and their operational experience in different accelerator laboratories**. Five laboratories have been contacted in July 2019, asking them to provide information about their experience on using Cs and their risk assessment.
- The laboratories contacted were: BNL, FNAL, J-PARC, RAL, and ORNL. The findings are summarized on Slides 21/22:
    - BNL, FNAL, and RAL use continuous caesiation. J-PARC uses a very frequent caesiation without beam interruption. ORNL uses single-shot caesiation based on a Cs collar integrated into the ion source.
    - All of these labs operate their Cs oven **above a temperature of 100°C**.
    - **None of these labs reported operational issues of the RFQ** that could be tracked down to Cs influx. However, there have been problems reported related to the valve following the Cs oven.
- An International review in 2018 was in favour of using continuous caesiation for LINAC4, mainly considering the operational aspects.
- Christoph Wiesner asked how the **consumption of Cs** is defined. Edgar Mahner replied that it is estimated based on the amount of Cs that enters the source, but there are no measurements of how much Cs leaves the source.

- Daniel Wollmann asked if the **equilibrium loss of Cs** from the source can be estimated as a function of the temperature. Edgar Mahner replied that the setup is too complex to be simulated easily because it would need to include the plasma and beam behaviour.
- Jose Antonio Ferreira Somoza suggested to add the **temperature of the plasma electrode** to the summary table as it is an important parameter for the Cs behavior.
- Daniel Wollmann asked how many **surface layers of Cs** are required for efficient source operation. Edgar Mahner answered that it is well known that a single layer of Cs should give the desired minimum work function, while more layers of Cs increase the work function again. However, in practice it is very difficult to control and simulate the surface deposition inside a plasma cell. Here, one relies on procedures and experiences.
- Rende Steerenberg pointed out that the **J-PARC experience** seems contradictory. On the one hand, no Cs issues in the RFQ and beamline have been reported. On the other hand, they state that the Cs leakage determines the high-voltage stability and that they have taken active measures to reduce the Cs leakage from the source (by decreasing the temperature of the plasma electrode from 200°C to 70°C). Edgar Mahner replied that this doesn't have to be a contradiction. Cs is lost from the hot surface of the plasma electrode, but it is not clear if this Cs actually goes into the beamline. Alessandra Lombardi added that, due to the operation mode, high beam losses occurred in the RFQ, which could have been the reason of sparking and high voltage (HV) problems.

1.4 Risk assessment for the RFQ (Suitbert Ramberger)

- Suitbert Ramberger presented the RFQ risk analysis on continuous-caesiation.
- A **general LINAC4 RFQ risk analysis** had already been performed in 2015 by Carlo Rossi and Maurizio Vretenar (EDMS No. 1560355).
    - Two Cs-related risks had been included in the analysis: contamination of the RFQ electrodes from a) normal caesiation and b) a caesiation accident. As mitigation, the hardware interlock of the sector valve was implemented.
    - Daniel Wollmann wanted to know how the maximum amount of Cs for an accidental caesiation was determined. Suitbert Ramberger answered that the amount of 25 mg is estimated from the volume of the ion source and that this amount might potentially be sufficient to degrade the RFQ voltage stability.
    - Following the recommendation of the review, no spare RFQ was built, but the required copper and stainless steel was purchased.
- At DESY, multipactoring in the DTL and glow discharge in the RFQ had been observed (J. Peters, 1998). Cs contamination was suspected as root cause, but couldn't be clearly demonstrated.
- One **monolayer of Cs** distributed on all inner RFQ surface would correspond to ~5 mg of Cs.
- The **mitigation strategy** in case of assumed Cs-related sparking issues of the RFQ would include:
    - Try to **recondition the cavity** (up to four weeks).

    - If no progress is observed after about one week, the RFQ would be cleaned by **water rinsing** (4 weeks if planned ahead).
    - An exchange, if a hot RFQ spare were available, would take ~2 weeks.
    - Rende Steerenberg wanted to know how long the water rinsing would take without previous planning. Suitbert Ramberger answered that this has not been checked in detail.
- David Nisbet inquired if a Cs contamination could be detected at an early stage by observing a **slow degradation of the RFQ performance**. Suitbert Ramberger reckoned that this is in principle possible, but that there exist also many other causes that can lead to RFQ sparking (e.g. hydrocarbon contamination). Edgar Mahner added that the RFQ is ~2 m downstream of the source and, thus, HV issues are expected to occur first on upstream elements in case of a significant Cs leakage.
    - Christoph Wiesner asked how the **maximum voltages and fields** at the ion source electrodes and the RFQ vanes compare. Alessandra Lombardi replied that this will be checked.
- Jan Uythoven concluded that the **impact for the RFQ could be a downtime of hopefully a few days and of 2 months in the worst case**.
    - Gianluigi Arduini emphasized that the main question is whether continuous caesiation significantly increases the risk when compared to pulsed caesiation and that it might well be that continuous caesiation is even safer due to the operation at lower temperatures.

1.5 Technical implementation and risk mitigation (Michael O'Neil)

- Michael O'Neil described the **implementation and the interlock features of the caesiation system**. The Cs reservoir is connected to the upstream side of the plasma generator via a gas transfer line. The line can be cut using a motorised valve. The three main elements (reservoir, transfer line, valve) can be heated independently.
- The system can be run in both **single-shot and continuous mode**. The two modes are mutually exclusive and require a physical key to switch between them.
- The following **safety features** are in place:
    - **Software level**: If one of the temperature readings from two independent PT100 sensors is above the software threshold, the PLC cuts the power to the heater supply, sets the reference voltage to zero and closes the Cs valve.
    - Hardware level: An independent **temperature relay** cuts the heater circuit if the temperature goes above the set hardware threshold.
    - An additional **thermal circuit breaker** is used to open the circuit if the current limit is exceeded.
    - Currently, the **temperature thresholds** are set to 83°C (software) and 85°C (hardware) for the reservoir and to 106°C (software) for the valves and transfer line.
- Daniel Wollmann asked if the hardware threshold on the temperature relay has to be adapted if one returns to pulsed caesiation. Michael O'Neil clarified that this is not required since the interlock is inhibited by turning the key.

- Daniel Wollmann wanted to know how long it would take for the **reservoir to cool down** after the heating was switched off. Michael O'Neil replied that it takes more than one hour to cool down to room temperature.
- All interlocks will be tested before the yearly start-up and after any modifications.
- The Cs valve takes 10 seconds to close. In case of a power cut, the energy stored in a capacitor is sufficient to still close the valve.
    - Daniel Wollmann asked if the **valve functionality** is checked regularly. Michael O'Neil agreed that this should indeed be foreseen. The test would be transparent to beam operation because a short closure would not change the caesiation noticeably. It was proposed to activate the valve on a weekly basis.
- Brad Schofield recommended to use UNICOS-CPC for the **control system**. This way it would be conform to the standards used for other process controls at CERN, and it would simplify the support and maintenance in the future. In addition, he remarked that the use of the newer PLC hardware generation (Siemens S7-1500 series) is recommended. Michael O'Neil responded that the 300 series has been used so far for LINAC2 and LINAC4. Therefore, it had been decided to continue the development based on these experiences. However, a migration could be envisaged for the future.
- David Nisbet asked who would have to be informed in case of a failure. Alessandra Lombardi replied that the caesiation system is part of the expert system of the ion source, but that the information is also available for the control system via FESA. Bettina Mikulec added that a **monitoring alarm** could be implemented to efficiently inform the experts.

1.6 Test Stand Results (Edgar Mahner)

- Edgar Mahner reported the **results achieved at the LINAC4 source test stand**.
- At the test stand, so-called **RFQ masks** were installed at the position where the RFQ would be located. They consist of copper plates with central holes to mimic the RFQ acceptance.
- The source was operated with **continuous caesiation for 5 weeks** in May/June 2019. For most of the time the Cs reservoir was kept at **temperatures between 60°C and 80°C**. The valve temperature was always kept 20°C higher than the reservoir.
- An initial degradation of the e^-/H^- ratio took place. Normally this is also visible during single-shot caesiation and is not fully understood.
- After the initial phase, the **H^- current remained stable while the e^-/H^- ratio reached very promising values below 1**.
- After the test, the RFQ masks were analysed with different surface techniques (XRF, XPS) with a detection limit down to 0.003 $\mu g/cm^2$ or 0.03 Cs monolayers. **No evidence of Cs was found on the RFQ masks and samples.** The Faraday Cup and the ion-source surfaces were not analysed.
- Federico Roncarolo inquired if the **shot-to-shot stability** might have deteriorated during the continuous caesiation test, even though the long-term stability has improved. Edgar Mahner explained that this had not been checked, but negative effects are not expected.

- The correct **interlock limit for the temperature of the Cs reservoir** was discussed.
    - Jan Uythoven asked how sure we are that interlock temperatures above 80°C are not required. Edgar Mahner replied that, based on the experiences at the test stand, he is confident that temperatures above 80°C are not required, and there might even be margin to reduce this limit.
    - Jan Uythoven reminded that other laboratories use much higher Cs oven temperatures, and that from the present test we cannot conclude on possible Cs contamination at higher temperatures. He pointed out that one could gain in operational margin by demonstrating that even at higher Cs temperatures (e.g. up to 100°C) no Cs can be found at the RFQ masks.
    - Alessandra Lombardi remarked that a too high Cs temperature could lead to an unstable source behavior.
    - Jose Antonio Ferreira Somoza suggested to calculate the maximum amount of Cs that could reach the RFQ based on the temperature and the geometry of the beamline.
    - Daniel Wollmann raised the question why the current interlock limit is not reduced, i.e. down to 75°C, given that the source performance was already very good during the test run at lower temperatures.
    - Alessandra Lombardi reminded that a certain operational flexibility is required for the LBE run.
    - Gianluigi Arduini suggested that, for the LBE run, the temperature limit could be set to a conservative value and, if required, the autopilot could be used to correct.

Jan Uythoven **concluded the meeting** thanking all speakers for their well-prepared presentations and all the participants for their contributions and the active discussion. He announced that the conclusion slides and MPP recommendations would be send out together with the minutes.

The findings and recommendations can be found on Indico.